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Review

Renewable Energy Sector in Bangladesh: The Current Scenario, Challenges and the Role of IoT in Building a Smart Distribution Grid

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Abstract: Advancement in electricity is the key ingredient that can actively take part in alleviating poverty and drastically improve the socio-economic status of the people of Bangladesh. The incorporation of renewable energy sources would help the country meet the energy requirement as well as contribute positively towards building a sustainable planet. The paper has extensively discussed the potential aspects of renewable energy resources in Bangladesh and how the Internet of Things can facilitate the implementation of intermittent sources. The regulatory and socio-economic aspects of the renewable energy industry have been explored and sustainable solutions will be discussed to fast-track the process of integrating various renewable energy sources in the power grid to meet the energy demand. The paper discusses the challenges associated with the RE integration in Bangladesh's power mix and tries to mitigate it through the IoT. Besides that, an RE map for Bangladesh along with prospective power network has also been discussed in this work.

Keywords: renewable energy; Internet of Things; distributed generation; solar; wind; nuclear; hydro

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1. Introduction

With the ever-increasing global population and urbanization, the electricity demand has skyrocketed [1]. It is paramount to understand the critical scale the world is at with coal-generated power and its impacts on the global climate and electricity market [2]. The "three Ds" (decentralize, decarbonize and democratize) in the energy industry across the globe are driven by the need to control the rapidly increasing carbon footprint and address the climate changes, mitigate the cost of electricity generation, restore aging electrical infrastructure and supply power to remote locations [3].

Researchers across the world are desperately seeking solutions to meet the growing energy demand without disrupting the earth's climate. Renewable energy sources such as solar, wind, hydro, biogas, nuclear, etc., have tremendous potential and are the solution to the existing electricity crisis and global warming [4]. The concept of smart grids is gaining fame and aims to exhibit extraordinary performance by establishing network stability, security and resilience [5–7]. The goal is to optimally allocate resources and enhance communication between the users and the resources. The Internet of Things (IoT) has drawn tremendous attention with its vision to extend the use of the internet and incorporate everyday objects [8]. The groundbreaking evolution would allow users to seamlessly connect with everyday use devices, communicate and remotely monitor them as required [9].

The integration of IoT and renewable energy sources marks the beginning of Smart Grid, a critical electrical network infrastructure that is crucial for the integration of intermittent energy sources [10]. IoT establishes the platform where the incumbent power network associates with a large-scale Information and Communication Technologies (ICT) network and creates the provision for renewable energy source integration. The Smart Grid is an innovative approach that would enable numerous objects such as smart meters, EVs, smart appliances, sensors, etc., to be interconnected and communicate to resolve any network issues [11]. With the help of IoT, the entire power grid infrastructure, starting from the transmission to distribution entities, will be geared with intelligent bidirectional communication ability and active monitoring and control of the electricity grid anywhere remotely with high precision and accuracy [12].

Developed nations, such as the USA, Australia, Netherlands, Belgium, Germany etc., have proactively stepped forward in the quest to fight global warming and embark on sustainable solutions. China, the USA and India are among the top three nations that have immensely invested in renewable energy sources [13–16]. The most commonly used renewable energy source is solar photovoltaics. Solar PVs are widely accepted and used across the globe in the urge to reduce the use of fossil fuels and fight climate change. South Australia is among the pioneers that opted for solar photovoltaics to meet its energy demands [17]. One in three households in South Australia has rooftop solar panels, which contributes approximately 9% of the total electricity generation in the state.

Developing nations, such as Bangladesh, Pakistan, Malaysia, Vietnam, etc., are incorporating sustainable energy resources to meet their energy demands [18]. The geographic location of Bangladesh gives the country numerous advantages to excel in sustainable energy production. Bangladesh is a country with endless potential and natural resources as well as manpower. The country is lacking a systematic approach to utilize its resources to address the issues that it is facing currently. With the majority of its population living below the poverty line, the country is still thriving to increase its economic status and has reached a GDP growth of 6% in recent times. The government of Bangladesh is prioritizing the power sector to boost its economy and has outlined both short-term and long-term power generation plans using both fossil fuels and renewable energy sources.

The IoT in general will play a vital role in renewable energy penetration to the current grid of Bangladesh. Integration of renewable energy and optimization of energy use are some of the key points for Bangladesh's power structure. The IoT offers a great flexibility in:

- Energy supply
- transmission and distribution network
- Smart metering
- Energy forecasting

Some of the factors which will be greatly affected are energy efficiency and reduction on the environmental impact. Energy theft could also be reduced by implementing such technologies [19].

At present, 74% of the entire population has access to electricity and reached a per capita generation of about 370 kWh. The government aims to establish an electricity infrastructure that will significantly utilize renewable energy resources to generate electricity before it completely runs out of the limited reserve of fossil fuels [20]. The nation aims to address the devastating outcomes of global warming and be among the countries that effectively participate in offsetting the carbon footprint.

Governing bodies have outlined the following strategies to meet the long-term energy target:

- fuel diversification
- energy efficiency improvement
- cross-border energy trade
- private and public sector participation
- construction of sustainable infrastructure

- extensive use of renewable energy resources

In order to achieve the above-mentioned goals, a well-devised plan is required, which includes the latest technology nodes to bring about comprehensive and sustainable economic growth in Bangladesh. As a result, it is necessary to determine the potential renewable sources in Bangladesh. Moreover, hindrances to grid integration of renewable energy sources need to be identified. In addition, the prospective power network of Bangladesh after integrating renewable energy-based distributed generation needs to be analyzed. After considering all of these things, the future energy generation vision and policies need to be fixed.

The main objectives and contributions of this review article are:

- Identify and summarize the potential and the most reliable renewable energy sources in Bangladesh
- Indicate the major obstacles to renewable energy penetration in Bangladesh
- Provide prospective IoT based distribution network of Bangladesh by integrating distributed generation
- Provide insight on new energy vision of Bangladesh
- Locate the high potential areas for Bangladesh to integrate renewable energy
- Identify the technical areas for distributed substation integration
- Outline the role of IoT in integrating renewable energy in Bangladesh's energy mix

2. Methodology of the Paper

For systematic research conduction, a well-planned methodology becomes the primary requirement [20]. The methodology followed to conduct this research work is shown in Figure 1. From Figure 1, it can be seen that the research methodology is mainly divided in three parts: Preparation Phase, Evaluation Phase and Outcome Phase. Details on these are provided in the following sub-sections.

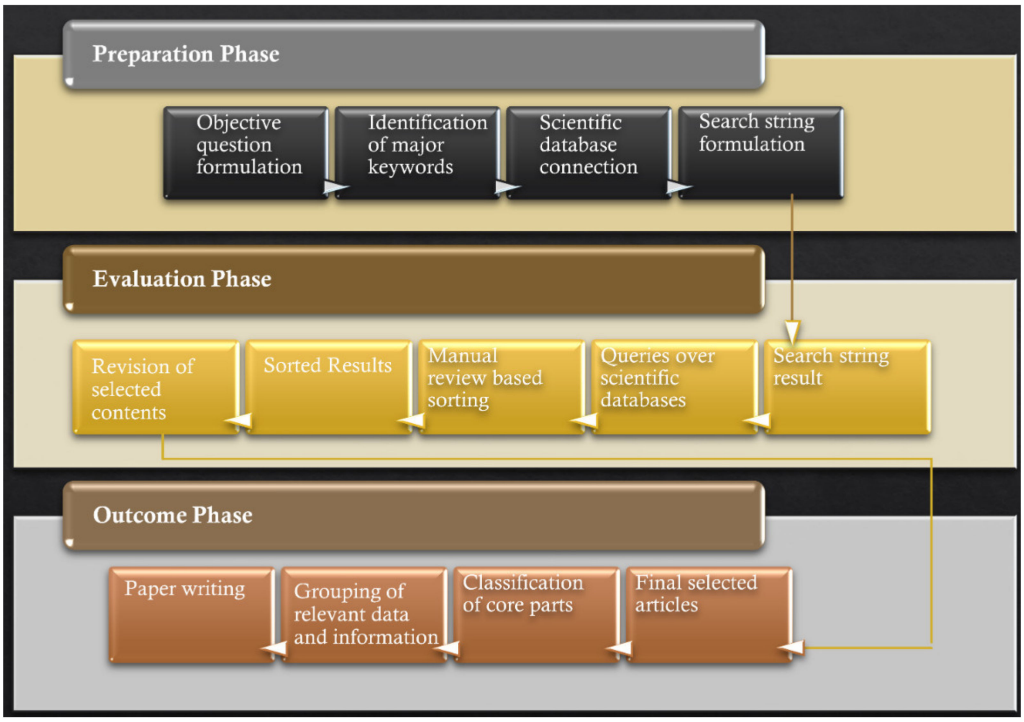

Figure 1. Review methodology.

2.1. Preparation Phase

Preparation phase works as the initial part of systemic research. In this phase, the objectives of the research are formulated. Then, to obtain the objective, a set of research questions oriented towards the main objectives are a formulated. The set of questions formulated for this research are:

- What are the most reliable renewable energy resources in Bangladesh?
- What is the current renewable scenario in Bangladesh?
- What are the main challenges and hindrances related to renewable generation and integration?
- How can IoT help in renewable energy generation and distribution?
- What are the future energy goals of Bangladesh?

After the research objective-oriented research questions are formulated, the major keywords are identified. The main databases for searching research papers are IEEE, Elsevier, Springer, MDPI, IET, Taylor & Francis and Sage publications. Furthermore, power and renewable energy related government websites are taken into consideration.

2.2. Evaluation Phase

The keyword and research objective related questions are used to search in the selected databases. After searching in the designated places, the obtained research articles, review papers and technical reports are reviewed. After the review process, only high-quality research materials are selected. These materials are further considered for a revision to reject any material that does to comply with the research goals.

2.3. Outcome Phase

In this phase, information is extracted from the selected research materials. The, the information is classified into several core parts. After that, relevant data and information are grouped together for writing a specific section or sub-section. Finally, through this systemic methodology, the paper writing part gets finished.

3. Renewable Energy Potential in Bangladesh

Since the major fossil fuel (natural gas) of Bangladesh is depleting rapidly, the government is looking to incorporate renewable resources into the system. As a result, a policy for effective utilization of renewable energy resources has been adopted by the Government of Bangladesh [21]. The focus of this policy is to shift the large dependency on conventional fossil fuel-based thermal power plants to renewable resources. Moreover, global depletion of fossil fuels, increasing cost of purchasing and hassles in importation are the major driving forces behind it. So, the necessity of harnessing energy from renewable resources is becoming a key factor to the country's development. Among different types of available renewable resources in Bangladesh, the most potential ones are discussed in this section. Arguably, nuclear is considered renewable by many researchers and policymakers. In this section, a brief discussion on the incorporation of nuclear power into the national grid of Bangladesh has also been discussed [22].

3.1. Solar Energy

A renewable energy policy was adopted by the government of Bangladesh in 2008 which aims to generate 10% of the total electricity from renewable energy by 2020 [23,24]. As Bangladesh is approaching the end of 2020 the country has not reached even 50% of the planned work. Electricity generation from renewable energy sources is about 3% of the total generation out of which almost 98% comes from solar PV [25,26].

In Figure 2, detailed data of solar irradiance of six major divisions of Bangladesh have been given [27]. Throughout the year, Dhaka has been receiving the highest solar irradiance, In April solar irradiance reaches the peak and plateaus during January. The least solar irradiance is in Hillary areas of Chattogram. On average, daily solar radiation varies from 4 to 6.5 kWh/m^2 in Bangladesh [27]. The Direct Horizontal Irradiance (DHI) guide is quite high in Bangladesh for which the potentiality to produce electricity from this abundant source is quite promising. Due to the geographical position, Bangladesh generally receives a good quantity of solar irradiance [28]. Solar radiation to Earth can produce about 1300 W/m of energy per hour. Though a good portion of this power is returned back as a reflection, still the amount of solar energy the Earth's surface retains is almost double of the non-renewable fossil fuel-based energy resources.

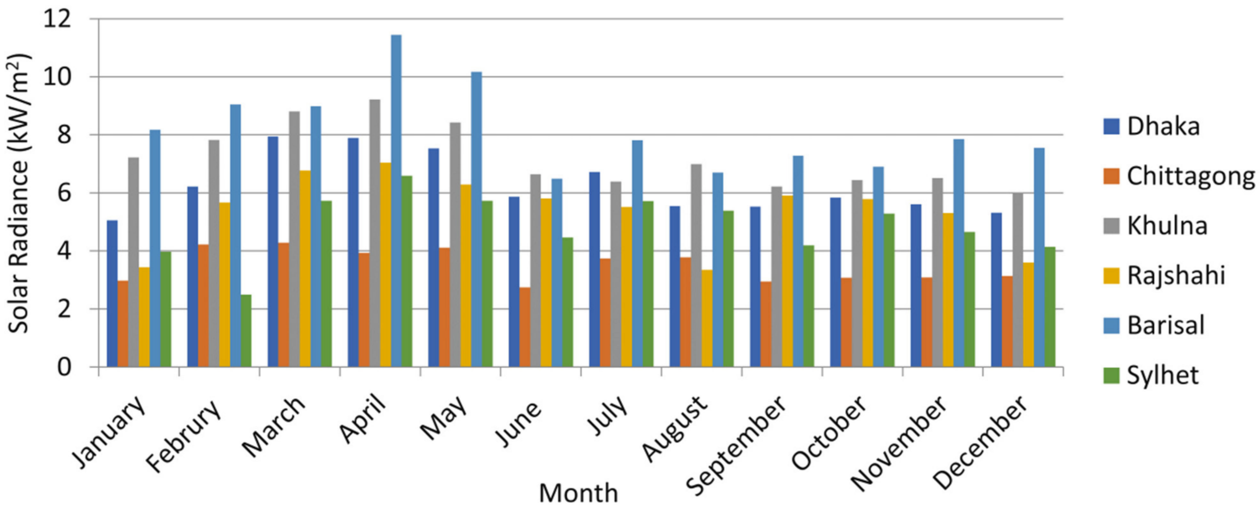

Figure 2. Monthly solar radiance in various divisions of Bangladesh [27].

Taking all these data into account, the Government of Bangladesh has taken an initiative to generate 500 MW electricity from this abundant source. Around 5.5 million Solar Home Systems (SHS) have been installed so far in the country. There are especially located in rural Bangladesh. SHS has efficiently replaced the use of kerosene-powered lanterns. This accounts for a USD 225 million saving every year and fulfilling 13% electricity demand of the total population [29,30]. Presently, a total of 367.95 MW of power is being supplied to the system from solar initiatives. USAID, UKAID, and many other international organizations have also distributed five thousand solar systems in Chittagong hill tracts where the Rural Electrification Board (REB) has not yet reached. Grameen Shakti, a Bangladeshi company is at the forefront of this initiative introducing an economic solar system back in 1996 [31]. Later in 1997, different organizations followed the way of promoting Solar to ensure the sustainable development of the country [32]. At the same time, the Government of Bangladesh has also established an Infrastructure Development Company Limited (IDCOL) on 14 May 1997 to promote, develop and finance renewable energy-based infrastructures [33].

Another successful project of the Government of Bangladesh has been the introduction of solar irrigation pumps. It has replaced the diesel-based water pump system in Bangladesh [34,35]. To reduce the emission of CO2 and dependency on fossil fuels, Bangladesh has implemented 1446 solar-based irrigation pumps with a generation capacity of 31 MW per hour. REB has set a target to build up 2000 solar irrigation water pumps by the end of 2020 which is financed by the Asian Development Bank (ADB). Even though a lot of work has been done in this sector, a huge number of diesel-based pumps still exist in the country. The government needs to focus on this sector by implementing a stricter policy that will replace 1.34 million diesel-based water pumps. This small change can save around 2.9 million tons of diesel every year [36]. Moreover, Bangladesh has 240,000 grid-connected electric pumps which can also be replaced by a renewable energy-driven water pump. Bangladesh has also established 11 mini-grids to provide electricity to the remotest part where transmission and distribution line installation is difficult and costly [37,38].

Another smart move in the urban area by Bangladesh is the utilization of rooftop solar energy [39–43]. In addition, some of the conventional approaches taken by Bangladesh is the installation of a 28 MW solar power plant (commissioned in October 2018 in Cox's Bazar) and various solar technology-based other projects such as 102,191 solar street lights, 152 solar drinking water systems and 1933 solar telecom towers [44–47]. Taking all these initiatives into account, Bangladesh aims to reduce 576,200 tons of CO_2 emission by 2020 [47].

3.2. Wind Energy

One of the most promising sectors in renewable energy in Bangladesh is wind. Both offshore and onshore wind farms are making a buzz in the energy sector to be the next big thing. The generation of electricity from wind energy is comprehensively utilized in countries, such as Germany, Australia, United Kingdom, Denmark, Netherlands, Russia, China, Japan, India and Indonesia [48]. A 19% growth has been observed in global wind power in the last five years. Currently, the total electrical power produced from wind energy is 743 GW [49]. The Global Wind Energy Council Market Intelligence is looking forward to installing a further 355 GW before 2024 [50].

The location of Bangladesh does suit wind power production. Bangladesh locates between 20°30′ to 26°38′ North Latitude and 88°04′ to 92°44′ East Longitude which gives a decent wind profile [51]. Moreover, a long coastline of 574 km in the Bay of Bengal can be of great potential to produce wind energy. In Bangladesh, south-westerly trade wind and sea-breeze blow in the summer season. During the winter months, gentle north-easterly trade wind occurs, due to which, land breeze blows. The prospect of wind energy in Bangladesh is more than 20,000 MW with an average wind speed of 7 m/s [52–54].

Figure 3 demonstrates the wind speed across Bangladesh. The Chittagong division has persistently been at the top of the chart in wind speed since 2005 [55–57]. Dhaka is towards the bottom of that group. This is mainly due to the fact that Chittagong is located in the coastal region of Bangladesh. Moreover, Bagura and Sylhet have decent potential to harness energy from wind. Wind speed is comparatively lower during the months of October to February. The highest wind speed is normally observed in June and July [55]. At a height of 30 m from the ground, in coastal areas of Bangladesh, the average wind speed is greater than 5 m/s annually [51]. Owing to this fact, Chittagong has a great potential to set up small and medium-sized wind farms. Cox's Bazar, Patenga, Teknaf, Kutubdia Char Fassion, Kuakata and other coastal areas of Bangladesh have better prospects of harnessing wind energy than other areas of the country [56,57].

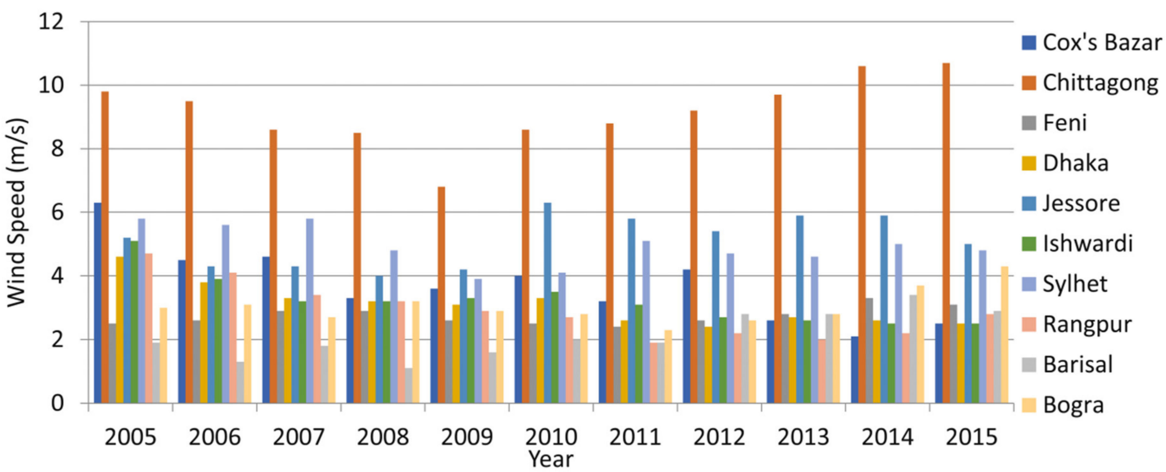

Figure 3. Wind speed in various potential districts of Bangladesh [51].

Bangladesh has taken initiatives to boost the wind energy sector. A grid-tied 0.9 MW and a standalone 1 MW wind turbine at Muhuri Dam and Kutubdia are the first initiatives by the government. BPDB wants to install another 100 MW farm by establishing a private-public partnership [51]. Furthermore, a 200 MW project is under the planning stage which will be located at Anwara Parky Beach in Chittagong [49–51]. Along with these BPDB has also targeted 22 hotspots across the country as potential wind energy installation zone. An NGO called BRAC and Grameen Sakti (a private company looking to establish renewable energy in Bangladesh) are also looking to enrich this sector by putting micro efforts through their organization. In the coastal areas of the country, Grameen Shakti installed two wind generators with a capacity of 300 W and 1 kW at a Shrimp firm in Chakaria, Cox's Bazar.

3.3. Hydro Energy

Bangladesh is a land of rivers. There are around 1.4 trillion cubic meters of water per year flowing through different rivers. Even though the land is fairly plane, high current flows through major rivers for six months of a year which provides some locations with a prospect of 10 kW to 5 MW power generation capacity [57]. The first hydropower unit installed in Bangladesh was a 10 kW mini-hydro in Bandarban in 1962. Another initiative, which was taken by the Pakistan government before the independence in 1971, was the Kaptai Hydroelectric Power Plant. To date, it has been the highest installed capacity (230 MW) hydropower plant in Bangladesh. In Table 1, A full list of potential locations of hydroelectric generation has been mentioned. Ranga Pani Gung in Sylhet has the highest potential with 616 KW generation capacity. Rangpur is another division in the country with many rives. This area has the potential to install mini hydro plants in seven locations. All these areas have been identified by the Bangladesh Water Development Board (BWDB). Besides these locations, there are several sites with good potential to install micro-hydro which have been listed in Table 2. Moreover, there have been few initiatives where Pico-Hydro units were taken into account to reduce the power scarcity in the villages of Bangladesh [58].

Table 1. List of potential small hydroelectricity sites in Bangladesh [57].

District	Stream/ River Name	Potential Electrical Energy (kW)
Chattogram	Foy's Lake	4
	Choto Kumira	15
	Hinguli Chara	12
	Sealock	81
	Lungichara	10
	Budiachara	10
Sylhet	Nikhari Chara	26
	Madhab Chara (1500 ft from fall)	78
	Ranga Pani Gung	616
Jamalpur	Bhugai-Kongsa (2 miles U/S. of Nalitabari P.S.)	69 kW for 10 months
	Marisi (at Dukabad near Jhinaigati Thana H.Q.)	48 kW for 2 months
Dinajpur	Dahuk (at Buabari)	35 kW for 10 months
Rangpur	Chawai (at U/Ss. of Chawai L.L.P)	20 kW for 2 months
	Talam (at U/S. of Talam L.L.P)	24
	Pathraj (at Fulbari)	32
	Tangon (at D/S of Nargun L.L.P)	48
	Punarbhaba (at Singraban)	11
	Buri Khora Chikli (at Nizbari)	32
	Fulkumar (at Raiganj Bazar)	48

Table 2. Potential micro-hydropower sites in Bangladesh [57].

Site	Expected Power Generation	Socio-Economic Infrastructure with 1 km Area		
		Household	School/Mosque/Clinic	Small Industry
Nunchiri Tholipara, Khagrachori	3	100	3	1
Chang-oo-Para, Banarban	30	200	5	2
Bangchari, Bandarban	25	600	12	5
Nunchiri Tholipara, Khagrachori	3	100	3	1

3.4. Nuclear Energy

The constantly increasing hike in the price of oil, coal and fossil fuels, as well as the depletion of natural gas reserves has alarmed the Government of Bangladesh. Hence The government of Bangladesh has been focusing on nuclear energy, as a result of which Bangladesh is set on becoming the 33rd nuclear power-producing country in the world by 2024 [59]. After the start of the Ruppur Nuclear Power Plant, it is expected to add another 2400 MW to the national grid.

Originally, the Pakistan government wanted to build a nuclear power plant in Ruppur, Pabna District back in 1961, but later decided to shift the project to Karachi. After the independence of Bangladesh, the government decided to start the project again. However, it took until 2009 to cross the planning stage [60]. There have been several amendments in the plan right from the beginning of the project in 1961. In 2007, a deal was signed between Bangladesh and China where China proposed to build 2 reactors of 500 MW and 1000 MW generation capacity. The total estimated cost of building proposed by China has been 2.5 billion dollars [61]. Besides China, Bangladesh has been in talks with a number of other countries regarding the nuclear power plant project. Finally, Russia won the contract in 2009 and has started the construction phase [62]. Even though Russia wanted to go for the latest technology, the Bangladeshi government opted for the VVER-1200 reactor [63]. The main agreement was signed in 2011 where Russia has agreed to build two 1000 MW Nuclear Reactors. Information on the Ruppur nuclear power plant is presented in Table 3.

Table 3. Ruppur 1 and Ruppur 2 nuclear power plant plan [57].

Type	Capacity (MW)	Start Year	Expected Operation	Plant Name
AES-2006/V-392M	1200 MW	2017	2024	Ruppur 1
AES-2006/V-392M	1200 MW	2018	2025	Ruppur 2

4. Challenges Related to Distributed Energy Resource Penetration in Bangladesh

With the ever-increasing growth in population, the demand for energy is soaring high globally. It is estimated by the International Energy Outlook that the demand for energy will increase more than 56% by the year 2040, worldwide. Researchers are turning towards renewable energy sources in order to satisfy the fast-growing energy demand and to reverse the consequences of global warming [64]. From 2005 until now, 144 countries have stepped forward to adopt policies and regulations that promote the integration of renewable energy sources within the incumbent system.

Despite the desperate need to address climate changes and environmental hazards, the penetration of renewable energy sources is challenging due to the political and regulatory framework that advocates the continued use of fossil fuels to meet the energy requirements. The literature addresses multiple barriers that hinder the utilization of renewable energy sources [65–67]. The barriers significantly involve social, economic, technological and regulatory aspects while cutting down the extensive use of fossil fuels for generation purposes to meet the demands. Table 4 provides a detailed study on different challenges related to renewable energy penetration in Bangladesh.

Table 4. Challenges to renewable energy penetration in Bangladesh.

Challenge Type	Challenges
Social [68–70]	• Lack of awareness among common people regarding renewable energy benefits • People often provide priority to utilize lands for agricultural and housing purpose rather than using it for renewable energy generation • Many people suffering from "Not in my Backyard (NIMBY)" syndrome renewable energy generation installation proposals within their neighborhoods, adhering their claims to landscape impacts and disruption in aesthetics of local communities
Economic [71–74]	• High-capital cost of initial installment which Bangladesh is unable to bear as per her current economy • Investors remain doubtful to invest money due to Bangladesh's lack of experience in large scale renewable energy generation • Investors are greatly demotivated as the return period is long and uncertain • Lack of proper economic infrastructure to provide economic support and easy condition loans to small scale renewable energy infrastructure setup • Lack of preferential finance to renewable energy setup over fossil fuel-based setup in government finance agencies
Technological [75,76]	• Lack of local industries that can produce PV cells, converters, generators and their supporting parts • Lack of skilled manpower • Lack of experience in large scale renewable energy generation • Lack of adequate knowledge regarding renewable energy setup, supporting infrastructure setup, operation procedure and regular maintenance • Poor R&D leads to mediocre procedures, guidelines and standards in terms of performance, durability, and reliability • Lack of energy storage capacity which is highly required in renewable energy generation since most of the renewable energy sources are weather and environment dependent
Regulatory [77–79]	• The policies regarding renewable energy development are quite ineffective • Government shows interest but has no effective strategy to reach the commitment and target regarding renewable energy development • Less incentives in renewable energy sector compared to fossil fuel-based power generation • Lack of proper coordination among the different regulatory and decision-making sectors • Lack of proper coordination between government and private sectors • Lack of revised policy guidelines prioritizing renewable energy generation
Resource Data [68,72]	• Comprehensive techno-economic analysis of large-scale solar power plant is yet to be done • Limited region-wise renewable energy potential data with seasonal variation measurements
Power Network [69,71–75]	• Existing power network mostly suites conventional fossil fuel-based energy generation, transmission and distribution. • Transmission and distribution networks are not updated and upgraded to handle distributed renewable energy generation • Smart distribution network to handle bi-directional power flow is yet to implement • Assessment of transmission capacity of existing power network to handle additional renewable energy sources is yet to be done • Lack of assessment study to determine grid capacity • Lack of proper feasibility study grid expansion and grid stability for integrating renewable energy resources • Lack of standard guidelines for renewable energy integration

Table 4. *Cont.*

Challenge Type	Challenges
Land [79]	• Limited availability of land due to huge population with high population density • Most of the available land are designated as agricultural land to feed the huge population. So acquisition of agricultural lands becomes quite difficult • No specific guidelines are made by the policy makers to separate agricultural and non-agricultural lands. So, investors find it difficult to identify suitable land • Lengthy and complex land acquisition process • Lack of proper support from different government and permission providing bodies to identify and approve specific land/zone for large-scale renewable energy projects • Lack of effective transportation and road infrastructures in remote areas
Environmental	• A large monsoon season makes it difficult to have PV in the energy mix • Even though Bangladesh has a large costal area, the speed varies and it is not very suitable for wind farm installation • Due to dams constructed in India and soil erosion, the big hydro plants are not that feasible anymore.
Security	• The power network is not at all secured in Bangladesh • Energy theft is huge; even though it has decreased over the years, it is still at a higher end compared to some developing nations • High penetration of IoT devices might bring in the issue of hacking • Denial of Service (DoS) or Distributed DoS (DDoS) attack is the worst for a Bangladeshi power system

5. Prospective Solution to Integrate Distributed Generation in Bangladesh's Power Network

In order to integrate distributed generation, proper infrastructure needs to be developed. For making the substation smart and to cope up with the data gathered and generated, IoT would play a key role. A distribution grid with embedded IoT sensors could solve the problem of power networks in Bangladesh. Power outage, energy theft, intermittent (hourly, diurnal, seasonal, annual variations) fluctuation of DG and frequency mismatch can all be handled by information gather at the data center from these IoT devices.

A prospective power network of Bangladesh after incorporating distributed generation is expressed using Figure 4. From the figure, it can be seen that industrial hydropower plants and nuclear power plants would be connected to the extra-high-voltage (HV) line of 230 kV rating by switchyard substation. A four-layer distributed substation should be added to the network for a smooth integration of the renewable energy in the system. Most of the distributed substation in Bangladesh is not IoT enabled, but a four-layer system architecture would allow for easy predictability and maintenance of the substation. On the other hand, SHS, wind and small hydro-based energy generation would require smart distributed substations where the main thrust of automation will take place. Moreover, the solar, wind, small hydro and nuclear energy plants will require constant monitoring and controlling mechanism for which IoT would play a major role. Sections 5.1– 5.4 would emphasize these topics. Section 5.5 provides a basic idea of a smart distribution network and IoT. Section 5.6 talks about IoT and energy storage.

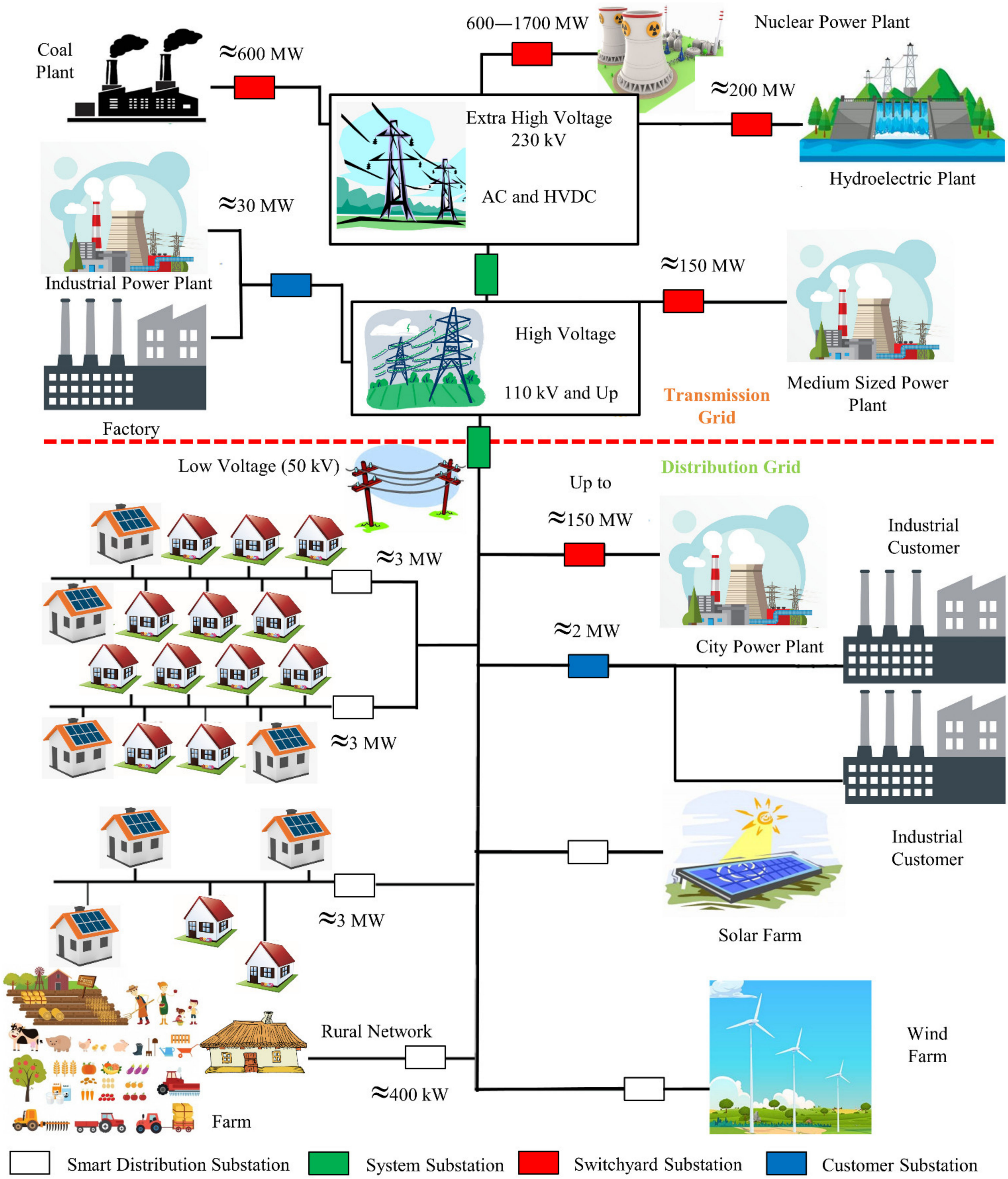

Figure 4. Prospective power network of Bangladesh after integrating renewable energy sources.

5.1. Wind Farm and IoT

As discussed in Section 3.2. It can be easily understood that wind energy has the potential to be incorporated into Bangladesh's power network. However, harnessing wind energy is not a simple task [80]. Large amounts of instruments, such as sensors, actuators, integrating strain gauges, bearing monitors and power conditioning technology, are required. Wind turbines are generally situated in remote regions, far from populated places. Therefore, for a country such as Bangladesh, it could be a big hassle as the infrastructure is still not suitable for this type of installation. In addition, wind turbines require constant monitoring and maintenance [81]. Fault in wind-powered systems may cause huge turbulence [82]. However, by introducing remote sensing and monitoring, especially by using IoT, it would be possible to bring wind into Bangladesh's energy mix. The unpredictability of wind-generated can be tackled by gathering data from environmental agencies and by forecasting the output. Data can be collected in smart distributed substations and the operation of complex modules, such as alternators, electronic controllers and cooling systems can be done remotely [83,84]. A control center can collect data from the wind turbines to recognize the asymmetrical patterns in the serviceability of the components and machinery, which would permit engineers to a hand to find a solution to any possible problem at the initial stage lessening the demand for direct manpower involvement.

Wind data can be collected in real-time and changes in power on the Internet, particularly through the Wireless Sensor Network can be determined (WSN) [85]. A basic block level representation of wind forecasting is expressed in Figure 5.

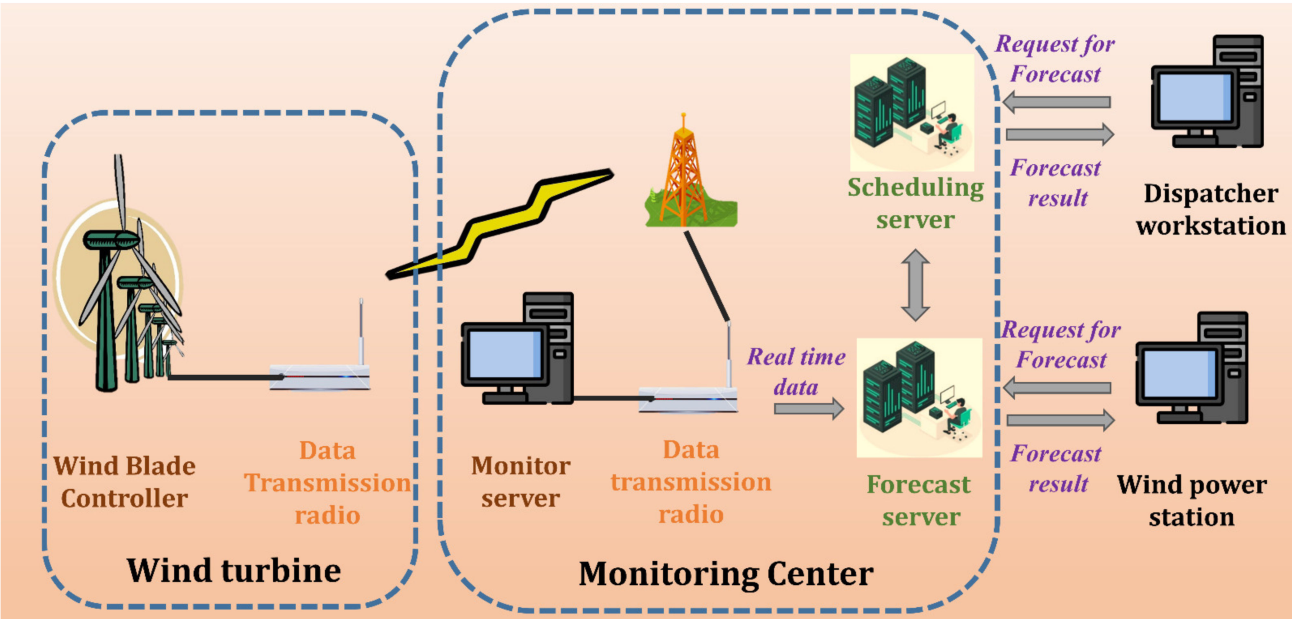

Figure 5. IoT-based wind power monitoring architecture.

The surveillance center senses real-time wind power information through the wireless sensor network and then transmits it to the prediction server in real-time. The results of the prediction server processing will be sent to the wind power plant, but can also be remotely sent to the scheduled server and then connected to the forecast results. A wind power plant and planning server for local monitoring and remote control thus achieve a wind energy prediction.

Given multiple considerations, the prediction server includes a short-term prediction, medium-term prediction and a set of prediction processing methods, including air temperature, pressure, the direction of the wind and humidity, to timely and efficient power across the whole system [86–88].

5.2. Solar and IoT

As solar has the most potential all across Bangladesh. Hence, PV-based systems have reached a new height due to which challenges associated with harnessing power from PV are required to be overcome [89]. The installation of new PV system means more endpoints to keep track of, where the systems could rely on manual monitoring previously [90,91].

IoT can solve one of the most important issues of unpredictability and bidirectional power flow when it comes to decentralized generation [92]. Sensors would have to be installed on solar panels to keep an eye on the performance and deliver real-time data to monitor the output, having remote controllability to operate and detect faults in the system [93]. Bangladesh is one of the most densely populated countries and cities such as Dhaka and Chattogram are full of high-rise buildings adjacent to one another. Due to this, unwanted shading and dust worsen the output of solar units. IoT-based sensors can monitor the dust and easily track the shaded percentage of a solar panel. IoT could also help Bangladesh to make a grid-tied PV system a huge success [93]. It can help in pinpointing the uncertainty and losses due to climate change, irradiance estimation error, dust and soiling, snow and ice effects.

The block-level architecture shown in Figure 6 maps the solar monitoring system components into the IoT paradigm. The perception layer represents the devices at the edge level which measure the performance of PV panels and environmental factors such as the atmosphere, air quality, etc. Such measurements are performed through a range of smart sensors interfacing with a computer element. Sensors include temperature, humidity, solar radiation, dust sensors, and current and voltage sensors, among other characteristics. The choice of edge interface usually depends on the complexity of the computer [94].

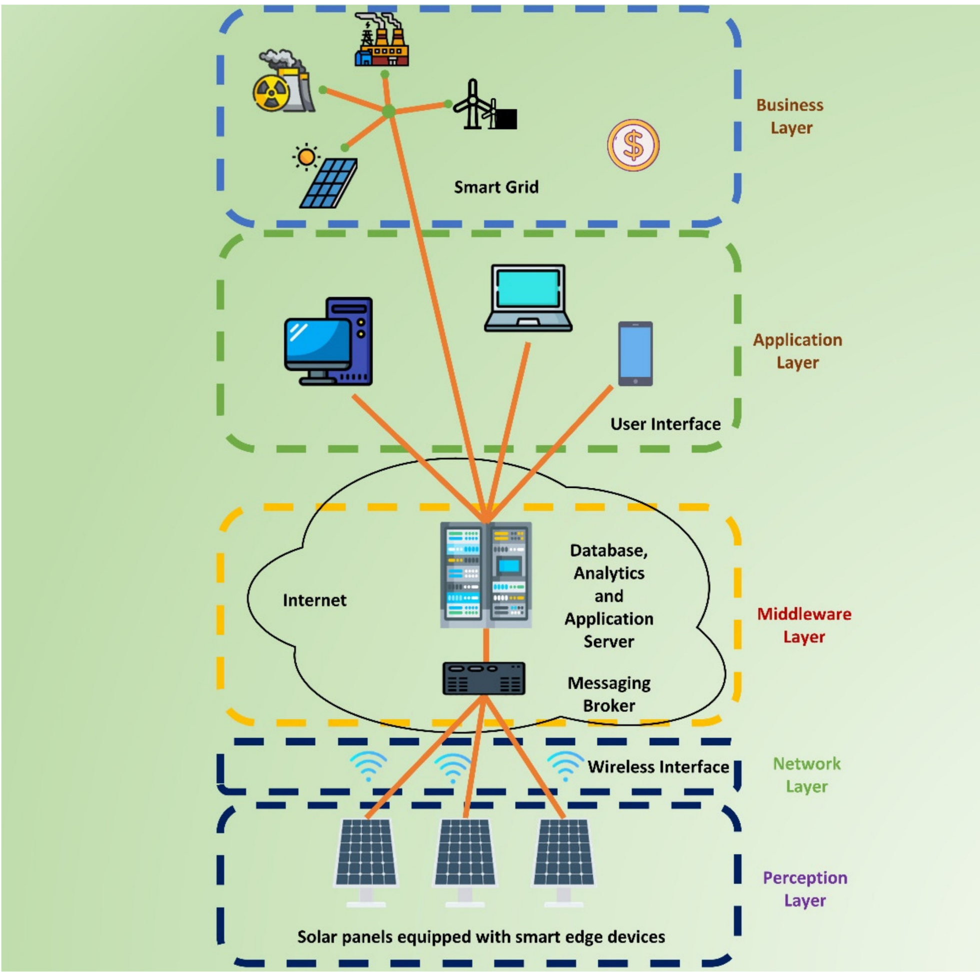

Figure 6. IoT-based PV power monitoring and control architecture.

Although basic microcontrollers such as Arduino Uno, ATXMega, ATmega328 or ESP8266 are sufficient to obtain and add sensor readings across a wireless network, a boundary computer system such as Raspberry Pi or BeagleBone provides an opportunity to conduct more advanced tasks on a borderline basis, such as system authentication and design analysis [95–97]. The edge is fitted with limited hardware to connect with a network system to the Internet using a little range wireless protocol such as WiFi or Zigbee system [98]. In order to provide direct connectivity through cellular networks, 3G/4G/5G and LTE may also be connected to the edge device [99].

Data obtained on a perception layer can be aggregated into the middleware layer through a wireless network to transform data collection, control, storage and networking technologies into comprehensive information that can be used in different applications. The middleware layer includes technology such as data aggregation messaging brokers, traditional databases such as SQL and NSQL databases, Big Data infrastructure such as Hadoop, web servers and analytics engines.

Information from the middleware layer is ready to be accessed by users, including network administrators and users through different application layer software interfaces such as computer applications, web browsers, and smartphone apps. Information can also be fed into a wider environment, including intelligent grid networks and enterprise and billing services. All over the device, the PV cell and environmental management functions, top-down information flows smoothly in PV system control applications, from the bottom up. In addition, low-level and high-level machine-to-machine (M2M) protocols, such as Wi-Fi, ZigBee, permit communication channels in a single layer between nodes, typically used in edge computing applications in the perception layer, and middleware level between data management systems.

5.3. Hydro Power and IoT

For a country such as Bangladesh, hydro could have been a potential solution to the energy crisis. However, only 2% of the total power generation today comes from hydroelectricity. A study conducted shows that Bangladesh can deploy hydroelectricity in its power grid. Many micro-hydro and pico-hydro could be implanted to harness this much-untapped sector. For Bangladesh, pico and mini-hydro power could break through its barrier by implementing it from the drains and houses. By tracking the exact time of water flow through IoT, load scheduling can be done. IoT can also play a big role in increasing the power output [100]. With IoT-based hydro units, the flow rate can be accurately monitored for which data would be collected in the central database from where a predictable power output could be achieved [101].

5.4. Nuclear Power and IoT

The power plant operation of IoT can play a vital role. In the beginning, the IoT sector mainly focused on consumer size, but as the industry has matured, it has started to play a vital role towards the industry up-gradation as well [102]. This allows the collection of huge amounts of data, hence making the industrial process smoother and predicting an outcome earlier than usual.

Nuclear plants must be at their maximum maintenance level constantly. Newer and older plants should be controlled and possible faults, most notably, should be identified as quickly and as feasibly as possible, in order to intervene immediately irrespective of the structural era. The IoT will gather and analyze data to contribute to ad-hoc activities. These can be communicated and used for maintenance, security and protection. Mobile data collection and transfer also provide more functionality for remote analysis, monitoring and automatic intervention of the plant and its emissions. Data collection and appropriate use will contribute to the improvement of the nuclear industry's performance, protection, and reliability. Finally, a more refined knowledge of the framework will predict the performance and properties of a plant.

The new IoT network management system has recently applied to run on heterogeneous 5G networks under varying conditions. The incomplete WSN sensor data have been problematic for several years [103]. Wireless networking, microelectronics and embedded computing systems were researched extensively by WSN, which is one of the IoT's key technology.

In the nuclear industry, there are drawbacks to the use of IoT technology—such as cyber protection and computer security. From the system design stage, these risks are covered. The tasks range from data storage, IoT computers, data analysis, data storage and robust control methods to a data center.

5.5. IoT in Distribution Network

The increase of rooftop solar panels, which are mandatory for all new structures for Bangladesh, has opened the door for the active distribution network. Bangladesh has mainly focused on deploying the SHS (Rural area) and rooftop solar system (Urban setup). small-micro and pico-hydro can also come into the picture in the near future. In many countries, these distributed generation sources are called virtual power plants or VPPs. In this situation, these VPPs can combine and act as a greater source of power. In recent times, most of the rooftop power generation units are tied with the main power line. However, as the grid is not yet ready, the generated power is not utilized. In the next 5 to 10 years this will play a vital role as the grid becomes smarter. The more efficient exploitation of these setups and the economical operation of conventional resources in the distribution networks must be operated by the local distribution network. Hence, an IoT-based home energy management system is in need where demand control management and the output of SHS and rooftop power sources can be monitored all the time by the authority and also by the customers.

Figure 7 demonstrates the block diagram of a prospective smart distribution grid architecture which is quite practicable for the current power network of Bangladesh. Smart distributed substations and an IoT-enabled distributed grid would be able to tackle the hurdles faced by the current power network of Bangladesh. All the big generation units have already been connected to a central database. In the proposed model, the consumer side and environmental agency of Bangladesh will have to connect to the database as well. In order to promote SHS and micro-hydro turbines in the city, IoT would play a vital role. Both renewable and conventional sources would be giving data to the data center for predictive control. Environmental agencies would be sending data to the central server so that energy output can be determined with the use of neural networks. Both transmission and distribution grids would be connected to the cloud for data analysis and self-healing. Industry, residential units and smart buildings ought to be connected to the cloud network so wide-area monitoring could be achieved to increase the reliability of the power system in Bangladesh.

5.6. IoT and Energy Staorage

One of the biggest challenges of an IoT device is to power them. During recent years, an exponential growth in IoT technology and efficient storage facility have paved its way to make IoT a viable solution. Hence, energy harvesting has become a huge area for researchers. This has not only increased the lifetime of the devices, but also the robustness. IoT devices with non-chargeable battery cells have been the biggest concern for this industry, as the battery taken up by the IoT devices increases as the lifetime of the devices also decreases. Hence, industry looked for a chargeable battery option in IoT. In order to do so, the flexibility of IoT devices got reduced. With the increase of the energy harvesting technology, many of the performance limitations would disappear.

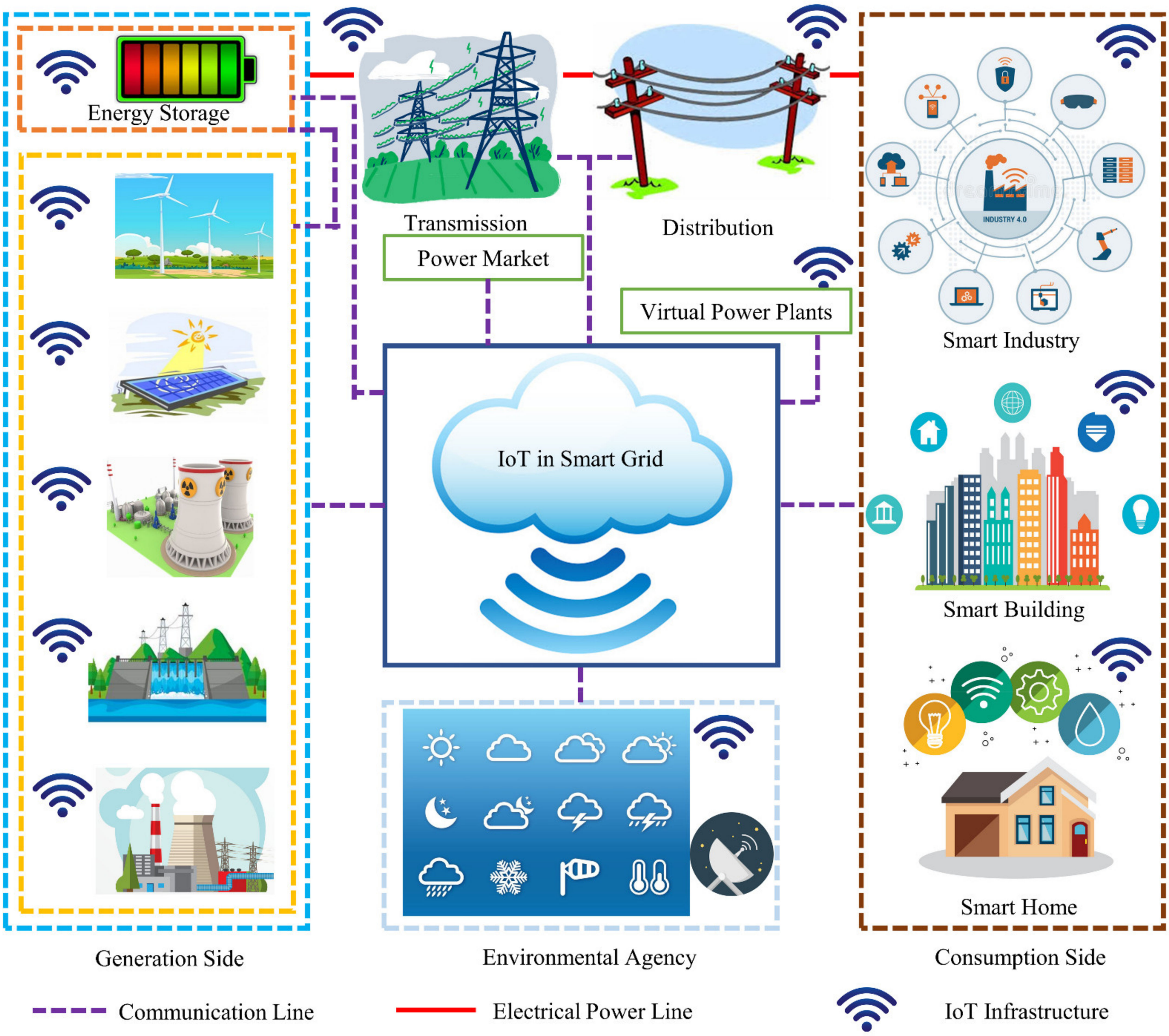

Figure 7. Prospective smart distribution network of Bangladesh.

6. Future Energy Technology and Proposed Vision 2041

The Government of Bangladesh is highly motivated to increase its energy generation as this would lead to the development of the economy as well as improve the living standards of its citizens. The government is committed in making electricity available and affordable across the country by 2041 [104–106]. The government is relying on the Rooppur Nuclear power plant that will be up and functioning by 2023. The plant is estimated to generate around 2400 MW of clean energy. The regulatory bodies are inclined towards offshore windmills to be constructed in Cox's Bazar to capture the wind and generate electricity. Solar is now leading among all the other renewable sources, and biogas and micro-hydro plants are being thoroughly discussed [107].

The 2041 vision has pushed both the public and private sectors to engulf in projects to improve the generation capacity. A meticulous plan is devised to boost electricity generation and meet the estimated goal of 57,000 MW of energy. Under the plan, 50 projects are under construction and forecasted to deliver 15,151 MW of electricity. In total, 15 projects with a capacity of approximately 4159 MW are at the signing stage, and 9 projects are at the tendering stage. The transmission and distribution networks are also drawing attention to meet the 2041 vision. The current transmission line is about 11,650 circuit kilometers and 524,000 km of the distribution line is active with the power network. Construction of a 18,126 km transmission line with 90,382 MVA capacity is proposed with 497,000 km of distribution network. In the short term, the government is focusing on importing 340 MW of power from neighboring countries, such as India.

The renewable energy sector is promising and many projects are under planning and development. 657 MW of solar power plants are under construction at various locations across the country including, Mymensingh, Sylhet, Mongla, etc. Around 300 MW of solar projects are under planning. A 30 MW wind power plant is under construction at Sonagazi and many other plants are at the planning phase. A 6 MW biogas-based power generation project is at the planning stage by private sector bodies. These projects are to increase as the country progresses and delivers completed projects.

Measures are taken to develop and utilize domestic resources optimally. Robust, top-quality network infrastructures are built to the ease transmission and distribution of energy and minimize losses. Human resources are closely monitored and trained, and administrative tasks are improved to stabilize the energy generation and supply. Sustainable energy production is to be maximized and their inclusion is to be made mandatory in the generation sector. Strict policies are to be established for energy security and reliability [108]. A cost optimization strategy needs to be standardized in the generation and distribution sector. A governing body and proper regulations and legislation would allow Bangladesh to overcome the energy crisis and come out on top of it by 2041.

7. Discussion

This work has been quite different from some of the other work in this area [109–111]. In [109], the authors only talked about the statistics of Bangladesh. However, no detailed of the findings were presented. In [110], the authors only discussed the solar integration in Bangladesh. In [111], the authors talked about the statistics and what could be its future potential. On the other hand, in this work, most potential avenues are discussed. Nuclear energy has also been taken in to consideration in this work. Besides that, a total comprehensive issue of renewable energy integration along with the help of IoT has been discussed in this work.

Even though after studying the data and all other related documents the authors could come out with challenges, there were still some critical issues which could not be eradicated. The first limitation was the data received were from the data published, but practically the solar roof installed in Bangladesh is less than what some of the data show, and there were no documents found to pinpoint the anomalies of this. Another shortcoming of the paper was that there are hardly any developing countries that have implemented IoT-based distribution grids, hence all the ideas came from developed countries. Besides these, the challenges of smart substation have also not been addressed in this study.

Figure 8 shows a map of Bangladesh where all possible renewable locations are mentioned. Rooftop solar, SHS, micro hydro, wind power (off-grid and grid tide), hydro dam and nuclear power have been marked in the figure. The Chattogram division has a great potential to have a hydro, wind and solar mix. Dhaka has done well in implementing solar rooftop projects and Pabna has the sole nuclear power station which is supposed to be operational by 2024. In order to have these installed, the traditional electrical power system in Bangladesh needs to go through a restructuring, with the establishment of an electricity market that encourages competition and efforts to ensure energy efficiency in a context of environmental sustainability. These issues forced electrical power companies, government agencies and the community to find a suitable solution in order to enable efficient, reliable and responsible energy production, transmission and distribution system. This work has focused on the existing power structure of Bangladesh and its potential to generate electricity from conventional and non-conventional sources. The importance of a smart distributed substation and the use of IoT has also been outlined in the work. The IoT and wireless network has touched us in every aspect of life. Similarly, the IoT has also found its way into substations and switching stations as the system is becoming rapidly distributed and utilities integrate more equipment with communication capabilities. Hence, the need for an IoT-enabled distribution grid is becoming more prominent. An IoT-enabled grid idea is becoming popular with utilities becoming communication enabled around the world. A huge transition in transmission and distribution system post-World War Two has been seen. This was owing to the fact that the unparalleled growth pushed the demand for electricity. Many leaders in that era saw the need for new technologies to play a bigger role in how the grid was controlled and managed. Similarly, in the network of tomorrow, a huge change is expected due to change in the demography of power-producing areas. Even though the full system would take a long time to be established, a prototype implementation is quite achievable.

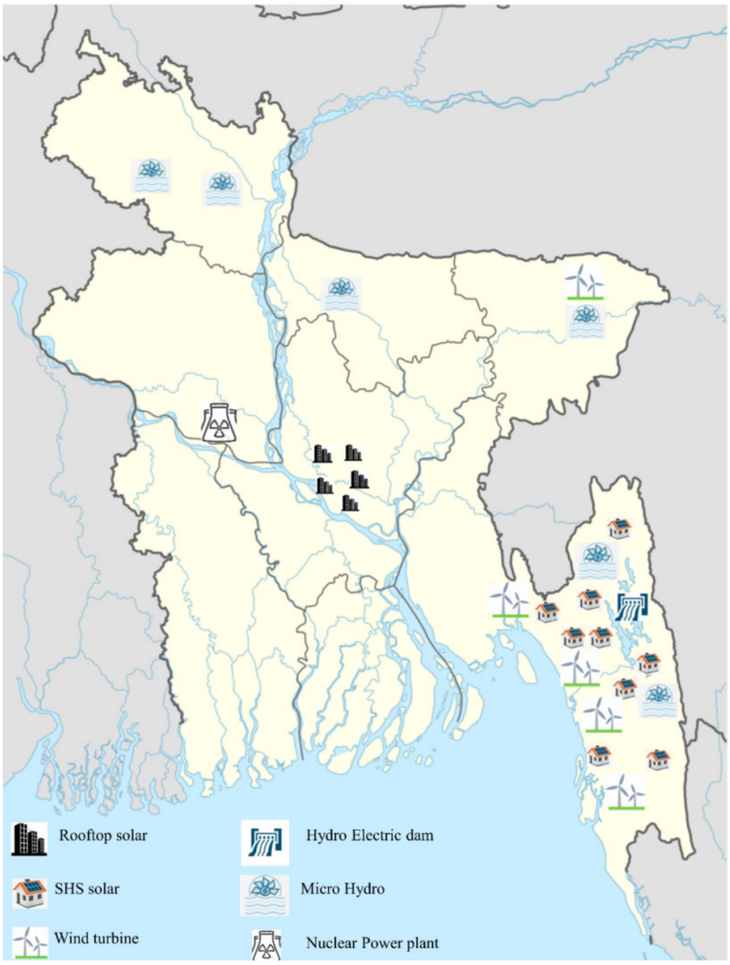

Figure 8. Map of Bangladesh and its renewable energy potential.

8. Conclusions

The review of the paper has identified and outlined some of the critical issues for Bangladesh. Even though PV, wind and micro hydro might look good in papers, some of the issues outlined in the work would raise some eyebrows. In spite of all the limitations, PV looks good for Bangladesh, whereas micro, hydro and wind still need to mature a lot for the Bangladeshi context. The paper also outlined the major obstacles and the way forward for Bangladesh to combat the issues. The paper also outlined the areas where Bangladesh should focus to increase it RE efforts. Besides that, an architecture for a smart distributed substation has also been discussed.

Climate change and global warming are real and have drastic impacts on the sustainability of the planet. Every little step towards fighting global warming can bring a difference and hopefully increase the longevity of life on Earth. Electricity is a major utility and has significant participation in the emission of greenhouse gases in the atmosphere. The world is striving to decarbonize, decentralize and democratize the electricity industry and the best way to achieve this is through the implementation of the renewable energy industry. Therefore, this research aimed to identify the most reliable renewable energy sources in Bangladesh. A thorough analysis of the existing literature provides insight that solar, wind, hydro and nuclear energy are the most reliable energy sources, other than fossil fuels. The prospective power network of Bangladesh after incorporating these electrical power generation sources has been outlined in this research. Moreover, a basic IoT-based prospective distribution network has been outlined. Finally, future insights, missions and visions of Bangladesh's government in the electrical energy section have been provided.

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